Edinburgh, Scotland
EURONOISE 2009
October 26-28

Noise absorption of gap graded mixtures with rubberized asphalt

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ABSTRACT

Sound absorption is a material property which contributes to reduce noise levels when sound propagates from the source to the receiver. Porous materials have particularly good absorption characteristics, not only because of the high percentage of air voids, but also due to their flow resistance and tortuosity. Road surface layers made of gap graded mixtures are among those absorptive materials. Because these mixtures have a void content that may be considered of medium level, this study aims to characterise their absorption capacity, particularly of those with rubberized asphalt binder. For this purpose, absorption measurements in a Kundt's tube were performed on cores extracted from slabs with different gap graded asphalt. In order to study the effect of the rubberized asphalt, the mixtures were produced in laboratory with two types of rubberized asphalt and with unmodified asphalt. The effect of the binder was pondered with this procedure. Furthermore, the effect of porosity was considered by comparing the results of mixtures which have considerably high and low void contents.

1. INTRODUCTION

The reduction of noise resulting from the interaction between tyres and road surface is an old issue which gained new relevance recently. It is a consequence of the traffic growth and of the inevitable approximation of hi-speed carriageways to the population.

The tyre-surface noise is a component of the total noise produced by vehicles, which prevails over the others for speeds from approximately 40 km/h [1] up to 110 km/h. The generation mechanisms depend, amongst other parameters, on surface characteristics such as aggregate gradation, texture, porosity, age, stiffness and distresses. Porous surfaces are very popular for traffic noise reduction due to their aptitude to absorb noise. They can reduce up to 6 dB(A) as opposed to a conventional layer.

On porous roads, sound energy is absorbed by the road surface due to its porosity. Sound waves enter by the upper layer of the road surface and are partly reflected and partly

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absorbed. The sound energy of the absorbed part is transformed into another type of energy. In roads this is mainly due to two effects: 1) by viscous losses as the pressure wave pumps air in and out of the cavities in the road; 2) by thermal elastic damping [2].

Noise absorption is influenced by road characteristics other than porosity, such as thickness of the porous layer and flow resistivity (indirectly determined by the stone grading). Furthermore, the absorption is influenced by the angle of incidence of the sound waves on the road surface.

To achieve maximum reduction of traffic noise, it is important to adjust the sound absorption properties of the road surface to the traffic composition. To assess, evaluate and optimise the sound absorption properties of road surfaces, it is necessary to perform sound absorption measurements [2].

The work presented herein is a part of one task of the ongoing project Noiseless - *Noise perception, modelling and abatement using innovative and durable pavement surface layers*. That task aims to characterize the absorption of all road pavement surfaces used in Portugal using the available and ongoing test methods.

Because surfaces made of asphalt rubber are currently the option most often used either in new or in rehabilitated pavements in Portugal, this work deals with those surfaces. Therefore, two types of gap graded mixtures were chosen, one with medium air voids (18%) and another with low air voids (less than 5%). The mixtures were made in laboratory with two types of rubberized asphalt binders: a) with high and medium percentage of rubber; b) with a "normal" asphalt binder. On the whole 6 slabs were constructed from where 72 cores were extracted and tested in the Kundt's tube both with dry and saturated cores. This procedure allowed not only assessing the effect of rubber on noise absorption, but also the effect of porosity, core thickness and wetness (this last effect will not be reported in this paper).

2. METHODS TO MEASURE THE SOUND ABSORPTION OF ROAD SURFACES

Sound absorption of road surfaces can be measured in various ways considering their characteristics. Each method may be applied for specific purposes. In what respects to their applicability they can be used either in laboratory, such has the Impedance Tube Method, or *in situ,* such as the Extended Surface Method and the Spot Method.

In the Impedance Tube Method, standing waves are created within a tube using a loudspeaker fed with sound waves (pure tones, sine sweeps, MLS sequences, etc.), which contains a test sample. Using the pure tone method, the maximums and minimums of the sound pressure in the tube are measured by using a microphone that can be moved along the length of the impedance tube. The standing wave ratio (SWR), i.e. the ratio of sound pressure maximums and minimums, is used to determine the sound absorption coefficient of the test sample at certain frequencies. Another most recent version of the impedance tube method utilizes the two microphone arrangement, in which the sound absorption characteristics are obtained from the frequency response between both microphones. It is commonly accepted that this method ensures circa 100 times faster results [3].

The Extended Surface Method [4] consists of a system composed of a sound source and a microphone at a fixed position from the sound source, which is placed over the road surface under test, or installed in a vehicle. It is based on free-field propagation of the test signal from the source to the road surface and back to the receiver, and covers an area of approximately 3 m^2. By means of a time window, the contributions of both the direct and the reflected sound are separated, and the sound absorption coefficient is calculated in one-third octave bands, from 250 Hz to 4 kHz. This method is appropriate for surfaces with a substantial sound absorption, such as porous asphalt surfaces [5].

The Spot Method is an *in-situ* method similar to the Impedance Tube Method. In this case the two microphone arrangement is used. A sound signal from a loudspeaker located at one end propagates through the tube. The open end of the tube is placed on the surface to be measured. The complex acoustic transfer function of the two microphone signals is determined and used to compute the normal-incidence sound absorption coefficient, from 250 Hz to 1600 Hz, and related quantities. This method is still being worked out to be used on surfaces of which sound absorption is relatively low, but must be measured or controlled [5].

The Impedance Tube Method has the disadvantage of requiring the extraction of samples while the others require traffic control.

The direct result of all methods is the sound absorption coefficient as a function of frequency. The typical absorption curves are characterized by:

- α_{max}: the value at which the measured absorption curve reaches its first maximum. It is related to the porosity and flow resistivity of the absorbing material;
- $f_{\alpha,max}$: the frequency at which the measured absorption curve reaches its first maximum. It is defined by the effective layer thickness of the material (given by the actual layer thickness and the tortuosity) [2].

3. STUDY

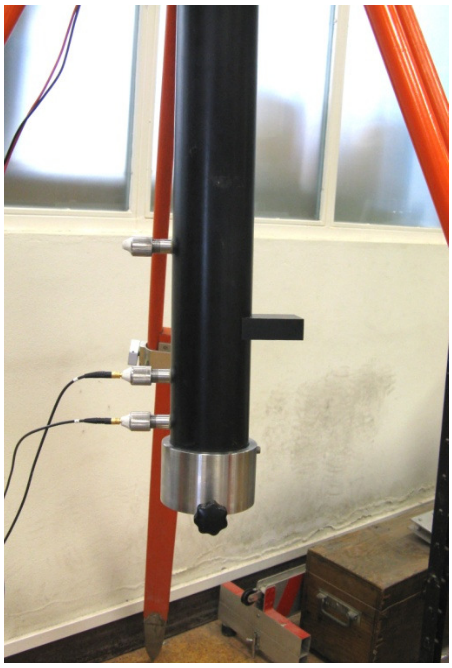
A. Methodology

For the analysis of the effect of rubber on absorption 6 slabs were constructed in laboratory. Each slab results from the combination of 2 types of gap graded mixtures and 3 types of asphalt bitumen. One mixture (GA) is characterized by a relatively high void content (18%) and the other (RA) by a low void content (less than 5%). The bitumens were characterized by high, medium and a zero percentage of rubber.

From each slab, 12 cylindrical samples with a diameter of 59 mm and 79 mm of thickness were extracted for acoustical analysis. Half of the samples were machine-cut to get 6 samples 30 mm thick (Figure 1).

To evaluate the normal incidence sound absorption coefficient of the mixtures, an impedance tube with 60 mm diameter and two microphones placed 45 mm apart were used. Due to the samples roughness, the distance adopted between the first microphone and the sample was 100 mm (about 1½ tube diameters). The impedance tube diameter and aforementioned characteristics imply a valid measurement frequency range between 250Hz to 3300Hz, covering the tyre-road noise generation frequency range between 500Hz and 2000 Hz.

a)



b)

Figure 1: Core extracted from slabs used for testing (a). Kundt's tube used to measure absorption (b)

The test signal selected was a MLS (maximum-length sequence) signal. According to ISO 10534-2 [6], the microphones were calibrated before testing, both in phase and intensity, by using a 100 mm thick mineral wool cylinder placed in the sample holder. Then, all samples were submitted to the procedures explained below, for dry and wet conditions.

For dry conditions the procedure adopted was the following:

1. The air temperature was measured;
2. The samples were put inside the sample older of the impedance tube, which fitted snugly inside. Any air gap found between the sample and the older was filled with modelling clay. Measures were also taken to ensure that there were no air gaps between the back of the sample and the sample older moving piston;
3. The samples were tested in the impedance tube, with the tube in the vertical position as shown in Figure 1 b).

B. Mixtures properties

The gap graded mixtures addressed in this study were formulated according to the European Standards. One of the mixtures is designated by GA (Gap graded Asphalt), with medium air voids (18%), and the other by RA (Rough Asphalt), with low air voids (less than 5%). Each one of these types of mixture was also formulated for a 50/70 base binder, which was modified with two percentages rubber (by asphalt weight): a) high percentage (hR%) - 18%; b) medium percentage (mR%) - 10%. For comparison purposes, two additional mixtures were formulated with the base binder. In the formulation procedure, aggregate grading, bitumen content and void content were kept the same for both mixtures as much as possible (Table 1 and Figure 2). The main differences between each mixture of the same type, which respect to the aggregate grading and the bitumen percentage, are a consequence of the need to “accommodate” the rubber.

The porosity actually achieved according to EN 12697-6 for each core is depicted in Table 2. As it can be observed there are differences between the porosity of the cores in the same slab that can reach 2%. It is a consequence of the compaction procedure. Furthermore, the 30 mm thick cores have generally a higher porosity despite the fact of being cored from the same slab as the 79 mm thick ones. That difference is a consequence of the rough surface of the cores.

Table 1: Properties of the mixtures.

Sieve size (mm)	High rubber percentage (hR%)		Medium rubber percentage (mR%)		No rubber	
	GA	RA	GA	RA	GA	RA
14	100.0	100.0	100.0	100.0	100.0	100.0
10	90.1	87.9	87.3	90.3	87.3	90.3
8	76.3	73.4	72.3	77.7	72.3	77.7
4	23.8	25.5	24.6	36.3	24.6	36.3
2	9.9	17.3	18.5	28.1	18.5	28.1
0.5	6.8	10.7	11.5	17.7	11.5	17.7
0.063	3.7	4.6	5.2	8.3	5.2	8.3
Bitumen content (%)	8.5	8.5	7.0	7.0	7.0	7.0
Rubber content (%) (asphalt weight)	18	18	10	10	0	0
Fibber content (%)	0.0	0.0	0.3	0.3	0.5	0.5

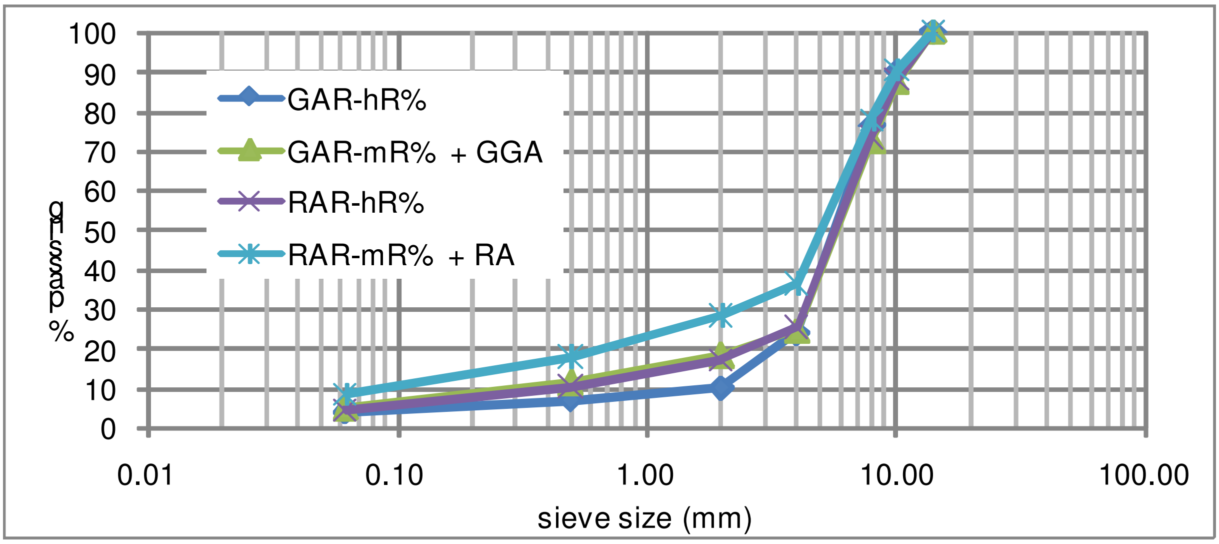


Figure 2: Grading curves of asphalt mixtures.

Table 2: Porosity of the cores.

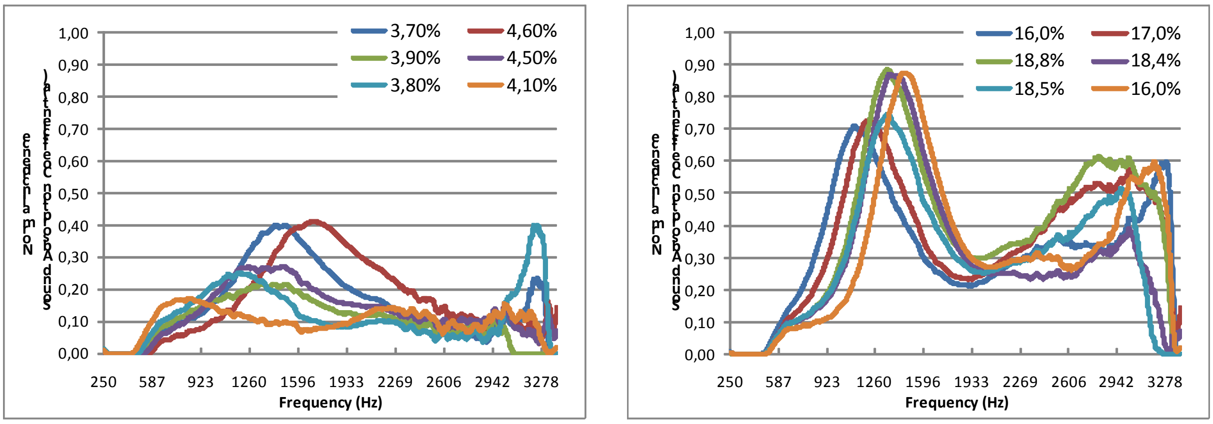
	Core	High rubber percentage (hR%)		Medium rubber percentage (mR%)		No rubber	
		79 mm	30 mm	79 mm	30 mm	79 mm	30 mm
Gap Graded asphalt	1	16.2	21.0	15.0	17.0	14.7	17.7
	2	15.8	20.3	15.0	18.8	14.3	18.8
	3	16.6	18.0	15.5	18.8	16.4	18.2
	4	16.9	19.4	13.7	18.4	15.2	17.4
	5	16.5	21.0	14.8	18.5	15.9	19.5
	6	16.5	20.9	14.7	16.0	16.3	18.7
	Average	**16.4**	**20.1**	**14.8**	**17.9**	**15.5**	**18.4**
Rough asphlat	1	4.8	7.4	3.5	3.7	2.8	2.6
	2	5.4	6.8	4.5	4.6	3.2	2.5
	3	4.5	6.5	3.0	3.9	2.4	2.5
	4	4.6	6.5	3.0	4.5	1.3	1.9
	5	4.4	5.9	3.4	3.8	1.5	2.2
	6	4.6	6.4	2.6	4.1	1.8	2.1
	Average	**4.7**	**6.6**	**3.3**	**4.1**	**2.2**	**2.3**

3. RESULTS AND ANALYSIS

The results obtained from the impedance tube measurements on the 30 mm and 79 mm samples are described in the following paragraphs. These results are presented in narrow band and 1/3 octave band frequency intervals.

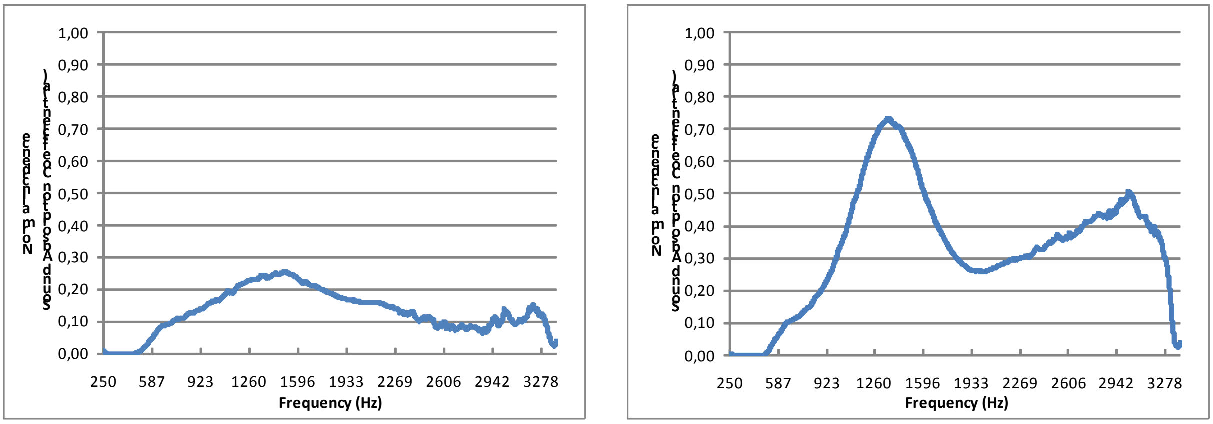
A. Influence of porosity and texture on sound absorption

The results gathered from all the samples showed that cores taken from the same slab presented distinct sound absorption characteristics. As an example, Figure 3 shows the frequency distribution of the normal incidence sound absorption coefficient, for six 30 mm thickness cores taken from slabs with 4.1% and 17.9% average air voids, both with 10% rubber content. Due to the conformation procedure in making the different mixture slabs, the variance of the density and percentage of air voids along the slab surface is inevitable. These differences, shown in Table 2, have influence on the variance in the normal incidence sound absorption coefficient (see Figure 3). However, this variation does not present a clear trend since cores with the same percentage of air voids have also different sound absorption characteristics. As reported by other authors, this is probably due, to the shape and texture of the different cores at the most upper layers. The different volumes of the air voids and the orientation of the aggregate (due to the conformation procedure and aggregate size composition) result in different resonant frequencies of these small “air chambers” which are clearly visible in the curves represented in Figure 3. Considering that the same slab has non-uniform absorption characteristics over its surface it was decided to arithmetically average the different absorption curves into a single representation of the whole slab. This is depicted in Figure 4 for the same percentages of air voids as in Figure 3.



a) b)

Figure 3: Dry cores with 10% rubber content and different porosities: a) 4.1% medium air voids; b) 17.9% medium air voids.



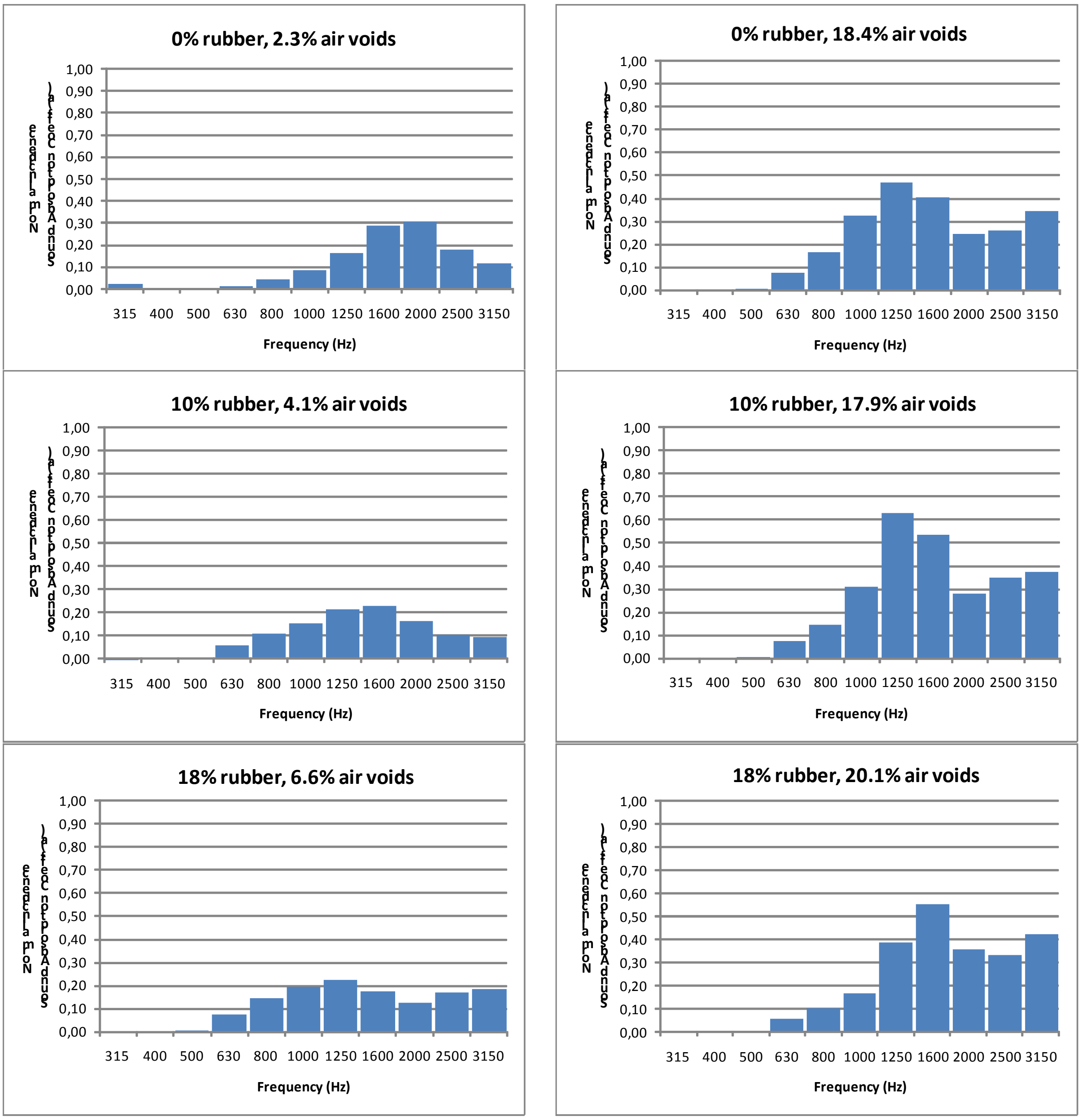
a) b)

Figure 4: Average values from 6 samples depicted in Figure 1. Dry cores with 10% rubber content and different porosities: a) 4.1% medium air voids; b) 17.9% medium air voids.

As expected, the normal incidence absorption coefficient is much higher in the high air void percentage samples. As it can be seen in Figure 4b) the peak value of the slab average absorption coefficient is approximately 0.73, occurring at 1385 Hz, in contrast to 0.25 in the low air void percentage samples, seen in Figure 4a). Additionally, it was clear from the several results obtained and seen in Figures 3a) and 3b), that the high air void percentage samples have a smaller dispersion of the peak absorption frequencies (when comparing different samples from the same slab), than that of the small air void percentage samples.

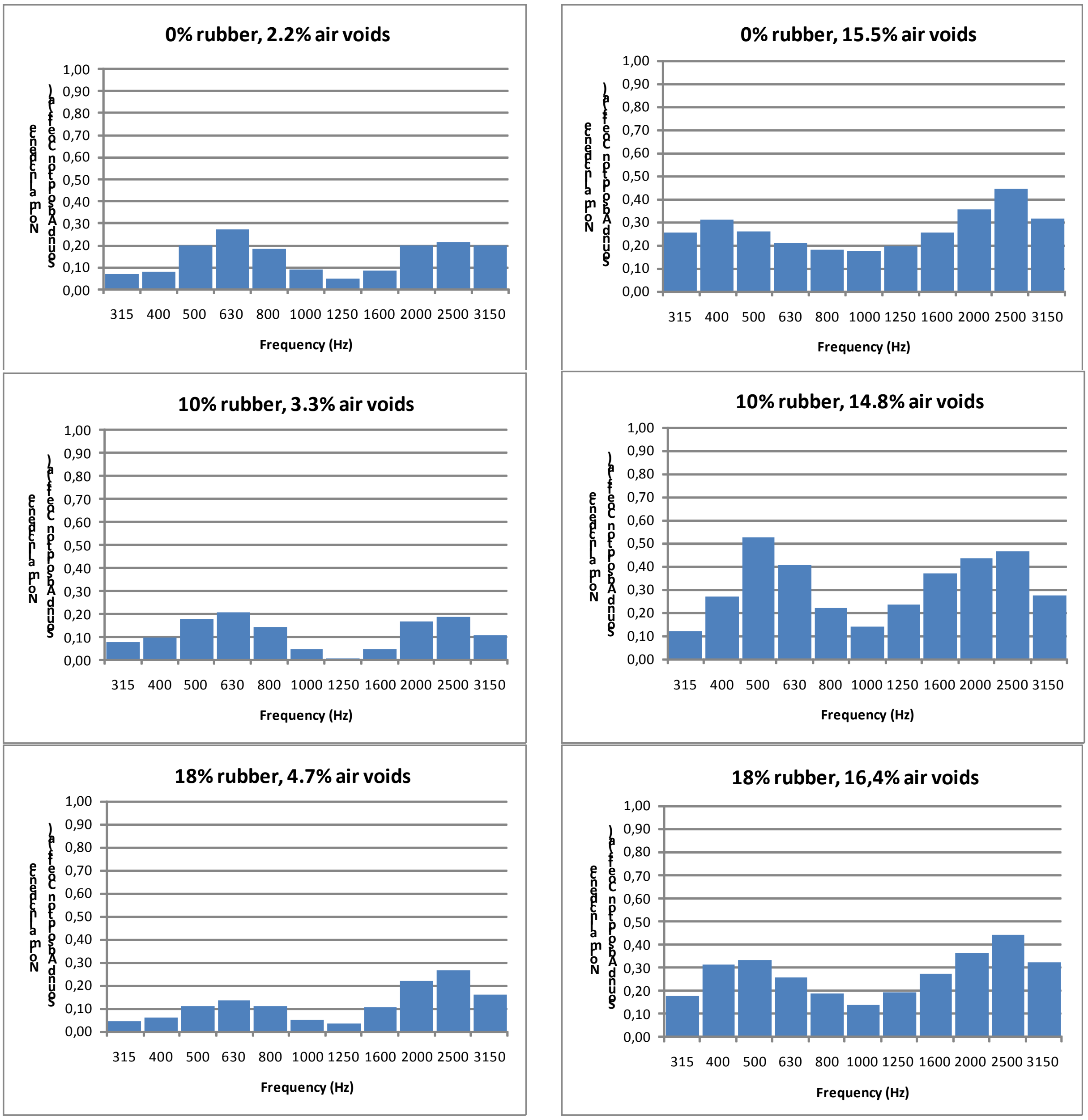
B. 1/3 octave band results

Figures 5 and 6 present the results of the normal incidence sound absorption coefficient obtained from all the samples, in 1/3 octave bands. Figure 5 relates to 30 mm thickness samples and Figure 6 to 79 mm samples.



a) b)

Figure 5: 1/3 octave band normal incidence sound absorption coefficient for 30 mm thickness cores with 0%, 10% and 18% rubber content and different average porosities: a) low average air voids; b) high average air voids.



a) b)

Figure 6: 1/3 octave band normal incidence sound absorption coefficient for 80 mm thickness cores with 0%, 10% and 18% rubber content and different average porosities: a) low average air voids; b) high average air voids.

Both 30 mm and 79 mm cores show higher sound absorption values for the higher air voids percentage samples, as already seen in Figure 3. However, the 79 mm thickness cores present much higher sound absorption at lower frequencies (down to 315 Hz) than the 30 mm cores, whilst in the smaller thickness samples, the minimum absorption coefficient starts at 630 Hz. This result is coherent with other more sound absorptive materials behaviour.

For the high air voids percentage samples, the 10% rubber content shows the highest degree of sound absorption. However, this result does not indicate that sound attenuation from mixtures using this rubber content is more effective. It is not necessarily the percentage that improves sound absorption. Sound generation from the tyre-surface interaction also benefits from a compatible tyre and road surface mechanical impedance which can be enhanced by adequate rubber content.

3. CONCLUSIONS

In this paper, the impedance tube method was used to evaluate the normal incidence sound absorption coefficient in gap graded asphalt mixtures with modified binder and in porous asphalt. In order to study the effect of the rubberized asphalt and porosity, the mixtures were reproduced in laboratory using different rubber contents and air voids percentage. Two different thicknesses of the cores were tested, 30 mm and 79 mm, which showed quite distinct behaviour, mainly in what respects to the sound absorption coefficient frequency distribution. As expected, thicker samples enabled much better absorption at lower frequencies in contrast with thinner cores. The results did not indicate a clear trend relating porosity with sound absorption, for similar air voids percentage. Nevertheless, the lower density samples showed higher sound absorption coefficients than the lower density ones. Interestingly, a 10% rubber content shows better sound absorption behaviour for the higher air voids percentage samples.

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